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FILING DATE: *July 19, 1996*
TITLE OF INVENTION:
METHOD AND APPARATUS FOR BLIND ACQUISITION OF DIGITAL COMMUNICATION SIGNALS IN THE PRESENCE OF SEVERE INTER SYMBOL INTERFERENCE
INVENTOR(S):
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PRIORITY DOCUMENT

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PATENT APPLICATION SERIAL NO. 60/022195

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PTO-1556
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Box Provisional Application
Assistant Commissioner for Patents
Washington DC 20231

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PROVISIONAL APPLICATION COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION under 37 C.F.R. 1.53 (b) (2).

JUL 19 1996

Docket Number	299.004US1	Type a plus sign (+) inside this box >	+

INVENTOR(s)/APPLICANT(s)

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Segal, Mordechai	Herzlia, ISRAEL
Shalvi, Ofir	Ramat-Hasharon, ISRAEL

ILX

TITLE OF THE INVENTION (280 characters max)

METHOD AND APPARATUS FOR BLIND ACQUISITION OF DIGITAL COMMUNICATION SIGNALS IN THE PRESENCE OF SEVERE INTER SYMBOL INTERFERENCE

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STATE	Minnesota	ZIP CODE	55402	COUNTRY	United States of America

ENCLOSED APPLICATION PARTS (check all that apply)

XXX	Specification	Number of Pages	8	______	Small Entity Statement
XXX	Drawing(s)	Number of Sheets	5	______	Other (specify) ______

METHOD OF PAYMENT (check one)

XXX	A check or money order is enclosed to cover the Provisional filing fees	PROVISIONAL FILING FEE AMOUNT	$150.00
XXX	The Commissioner is hereby authorized to charge any additional required fees or credit overpayment to Deposit Account Number: 19-0743		

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

XXX No.

___ Yes, the name of the U.S. Government agency and the Government contract number are: ______

Respectfully submitted,

SIGNATURE [signature] Date July 19, 1996

TYPED OR PRINTED NAME Timothy E. Bianchi REGISTRATION NO. 39,610

___ Additional inventors are being named on separately numbered sheets attached hereto.

PROVISIONAL APPLICATION FILING ONLY

60/022195

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re **PROVISIONAL** Patent Application of: Mordechai Segal et al.

Title: METHOD AND APPARATUS FOR BLIND ACQUISITION OF DIGITAL COMMUNICATION SIGNALS IN THE PRESENCE OF SEVERE INTER SYMBOL INTERFERENCE

Docket No.: 299.004US1

MAIL ROOM JUL 19 1996 EXP 10

BOX PROVISIONAL APPLICATION
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We are transmitting herewith the following attached items (as indicated with an "X"):

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By: [signature]
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By: [signature]
Name: Jonathan Ferguson

(NEW FILING)

METHOD AND APPARATUS FOR BLIND ACQUISITION OF DIGITAL COMMUNICATION SIGNALS IN THE PRESENCE OF SEVERE INTER SYMBOL INTERFERENCE

FIELD OF THE INVENTION

The present invention relates to digital communication methods and systems.

BACKGROUND OF THE INVENTION

Modems for digital communications systems are designed to cope with various channel impairments. An essential element of the modem is the start-up process in which modem parameters such as equalizer taps, carrier frequency error, timing error, and gain setting, are estimated in order to provide the required modem performance.

In the prior art, two training modes are used: 1) using a known transmitted data sequence; 2) or using the transmitted information data without any prior knowledge of the value of the transmitted data. The latter mode is known as blind start-up.

In the prior art, it is difficult to perform a blind start-up process, with limited computational resources and to converge to a good initial setting of the modem parameters for channels that exhibit severe linear distortion which gives rise to severe inter symbol interference (ISI), and channels that suffer from severe narrow-band interference.

The present invention seeks to provide method and apparatus for blind start-up process of a receiver in the context of digital communications signals in the presence of severe ISI and severe narrow-band interference. The present invention can be implemented using resources that are comparable to the implementation of conventional blind modems.

SUMMARY OF THE INVENTION

The present invention is a method and apparatus for blind digital communication receiver which is capable of operating over channels with severe ISI and narrow-band interference, using resources that are comparable to the implementation of conventional blind and non-blind modems.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 depicts a digital communications system which employs the invention in a preferred embodiment.

Figure 2 describes the transmitter in the preferred embodiment of Figure 1.

Figure 3 describes the structure of the receiver in the preferred embodiment.

Figure 4 describes the operation of the pre-equalizer filter unit of the receiver in the preferred embodiment.

Figure 5 describes operation of the DFE (Decision Feedback Equalizer) in the receiver of the preferred embodiment.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

In the following detailed description of the preferred embodiment, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration a specific preferred embodiment in which the invention may be practiced.

Reference is made to Figure 1 which illustrates a typical application of a digital communications system operating over UTP (Unshielded Twisted Pair) copper cables plant *102*. The system comprises of:

- A transmitter *101* that receives a sequence *104* of data bits b[n], and outputs a signal x(t) to the cable.
- A copper cable plant *102*.
- A blind receiver *103* that receives a signal y(t) from the cable plant and outputs a sequence of detected data bits $\hat{b}[n]$ *105*. b(n)

The cable plant may have one or more unterminated wire drops, as illustrated in Figure 1, and these wire drops may cause severe reflections that distort the signal and introduce significant ISI

Reference is made now to Figure 2, that describes the structure of the transmitter . The transmitter operates according to a general approach of linear transmission that particularly include PAM, QAM, PSK, CAP, and NRZ transmission methods. The input data bits sequence b[n] is converted to a sequence of I-Q complex valued symbols, a[n], by a bit to symbol conversion unit *201*, that may comprise a scrambler, a differential encoder, a trellis or a block FEC (Forward Error Correction) encoder, a CRC error protection encoder, a framer, a shell mapper, and a protocol layer units.
The sequence a[n] is then fed to a cascade of transmission filter *202*, an up converter *203*, where it is multiplied by sine and cosine sequences that are generated in the sine wave source *204*, a Digital to Analog (D/A) converter *205*, an analog LPF (Low Pass Filter) *206* whose cutoff frequency is designed to reject aliasing effects of the D/A, and an amplifier *207*. The output of the transmitter is the analog signal x(t).

Reference is now made to Figure 3 which illustrates the structure of the blind receiver. The input to the blind receiver is an analog signal y(t) that has propagated through the copper cable plant. This signal may suffer from severe reflections and linear distortions and it may contain high level of noise and interference components due to e.g. narrow-band radio transmissions which occupy the same frequency band of the signal y(t).
The receiver input signal is low-pass filtered by the LPF *301* which is designed to combat sampling aliasing effects, then it is amplified by a amplifier *302* whose gain is automatically adjusted to exploit the dynamic range of sampler, and then it sampled by Analog to Digital converter (A/D) *303*. The sampling phase of the A/D is adaptively

controlled by a timing PLL (phase locked loop) *304*, which adjusts the sampling phase so that the power of the A/D output is maximized. The timing PLL *304* may alternatively employ other conventional timing methods, such as decision directed timing.
The A/D output sequence is then down-converted by multiplying it with a sine and cosine sequences that are synthesized in a sine wave source *305*, and then the resulting I and Q components are low pass filter by the LPFs *306* and *307*. Both LPFs *306* and *307* are designed to remove the demodulation image and to match the response frequency of the cascade of the transmission pulse *202* and a typical cable plant.
The LPF units outputs are then processed by a pre-equalizer filter unit *307* and Decision Feedback Equalizer (DFE) unit *308* whose operation is described later in the sequel. The output of the DFE unit 308 is a sequence of detected I-Q symbols $\hat{a}[n]$. This sequence is processed by a symbol to bits conversion unit *309* that performs the inverse function of the bits to symbols conversion unit *201* and may employ a descrambler, differential decoder, FEC decoders, deframer, shell demapper, and a protocol layer decoder. The output of this unit is a sequence of the detected data bits $\hat{b}[n]$ *105*.

$\hat{b}_n$

Figure 4 illustrates the pre-equalizer filter unit. The input sequence of the unit, $s_4[n]$ is filtered by a digital FIR (Finite Impulse Response) filter *401* with L taps $p_n[1]...p_n[L]$ (L≥0) where $p_n[l]$ denotes the *l*-th tap after n iterations. The taps of the filter are adaptively adjusted by an adaptation unit *402*. The adaptation rule is

$$p_{n+1}[l] = p_n[l] + \Gamma_n(s_2[n])s_1^*[n-l] \qquad l = 1..L$$

where $s_2[n]$ is the output of the FIR filter, and where $\Gamma_n(x)$ is a possibly non-linear function whose parameters may vary with the iteration index n. A recommended class of Γ function is:

$$\Gamma_n(x) = \delta_p[n] \cdot x$$

where $\delta_p[n]$ is a sequence of step-sizes.

Figure 5 illustrates the DFE. The DFE's input sequence is first rotated by an adaptive rotator *501*, by an angle $\theta[n]$. The rotated sequence is then filtered by an FFE (Feed Forward Equalizer) FIR filter *502* whose taps' values are $c_n[1]..c_n[M]$ $(M \geq 1)$, and then it is summed with the output of an adaptive DFE FIR filter *504* whose taps are $d_n[1]..d_n[N]$ which is driven by the sequence of detected symbols $\hat{a}[n]$. The result of this summation is the equalized sequence $s_3[n]$, *506*. The sequence *506* is fed to a symbol detector that employs a memoryless nearest neighbor decision rule, based on the transmitted symbols constellation to generate the sequence $\hat{a}[n]$. We note that in this preferred embodiment a single memoryless decision rule is employed. However, the present invention can be employed in a receiver that employs a more accurate detection scheme such as an approximate nearest sequence detector which is the maximum

likelihood sequence estimator when the noise of the input of unit *503* has a Gaussian distribution.
The parameters of units *501*, *502* and *504* are jointly updated to combat ISI and noise.
The adaptation scheme is the following:

$$\theta[n+1]=\theta[n]+\rho_n(s_5[n]) \quad c_{n+1}[m]=c_n[m]+\varphi_n(s_5[n])s_3^*[n-m]$$

m = 1...M

$$d_{n+1}[i]=d_n[i]+\Psi_n(s_5[n])\cancel{Q}[n-i] \qquad i=1...N$$

$\hat{a}^*$

where $\rho_n(x)$, $\varphi_n(x)$, and $\Psi_n(x)$ are possibly non-linear complex valued scalar function whose parameters may depend on the iteration index n.
The adaptation functions in this embodiment are:

$$\rho_n(x)=\begin{cases}\delta_\theta[n]\left(\mathrm{Re}^2(x)-k_2\right)\mathrm{Re}(x)\mathrm{Im}(x) & n<T_1^\theta\\ \delta_\theta[n]\mathrm{Im}\left(\cancel{Q}(x)x^*\right) & n\geq T_1^\theta\end{cases}$$

$\hat{a}$

$\hat{a}$

$$\varphi_n(x)=\begin{cases}\delta_c[n]\left(x-\cancel{Q}(x)\right) & n>T_2^c\\ \delta_c[n]\left(|x|^2-k_1\right)x & T_1^c\leq n<T_2^c\\ \delta_c[n]\left(\mathrm{Re}^2(x)-k_2\right)\mathrm{Re}(x) & n<T_1^c\end{cases}$$

$\hat{a}$

$$\Psi_n(x)=\begin{cases}\delta_d[n]\left(x-\cancel{Q}(x)\right) & n>T_2^d\\ \delta_d[n]\left(|x|^2-k_1\right)x & T_1^d\leq n<T_2^d\\ \delta_d[n]\left(\mathrm{Re}^2(x)-k_2\right)\mathrm{Re}(x) & n<T_1^d\end{cases}$$

where $\delta_c[n]$, $\delta_d[n]$ and $\delta_\theta[n]$ are sequences of real-valued step sizes, where k_1 and k_2 are real valued scalars, and where $\mathrm{Re}(\cdot)$ and $\mathrm{Im}(\cdot)$ denote the real part and the imagenary part of a complex scalar, and where $\cancel{Q}(x)$ is the result of a memoryless nearest-neigbor symbol detector whose input is x.

$\hat{a}$

$\hat{a}$

We note that the sequences $s_1[n] \ldots s_5[n]$, $\hat{a}[n]$ may be calculated at the symbols rate (T-spaced receiver). Alternetively $s_2[n]$, $s_3[n]$ and $s_4[n]$ may be calculated at a higher rate (Fractionaly spaced receiver).

We Claim:

1. A digital communication receiver, comprising:

an analog front end unit;

a digital front end unit;

a digital equalizer, comprising:

a first filter capable of reducing the eigenvalue spread of the input spectrum;

a second filter capable of reducing the amount of noise and ISI without training data;

a rotator, if needed, capable of restoring the phase of the input data without training data;

and a nonlinear feedback scheme for removing the ISI without training data, if needed;

a symbol detector;

and a symbol to bit converter.

2. The communication receiver according to claim 1 wherein the first filter is an L-tap Finite-Impulse-Response (FIR) Filter, where L≥1, whose first tap is set to a fix value, and the filter's taps are adjusted so that its output power is minimized.

3. The communication receiver according to claims 1&2 wherein the second filter is an M-tap FIR filter whose taps are adjusted according to the following formula:

$$c_{n+1}[m] = c_n[m] + \varphi_n(s_5[n])s_3^*[n-m] \qquad m = 1 \ldots M$$

where $c_n[m]$ is the m-th tap of the second filter after calculation of n outputs, $s_3[n]$ is the input sequence to the second filter, $s_5[n]$ is the sum of the output of the second filter and the decision feedback filter, and $\varphi_n(\cdot)$ is a complex valued function, whose parameters may depend on the symbol index n.

and the decision feedback scheme, if needed, is a standard N-tap backward FIR filter whose taps are adjusted according to the following formula:

$$d_{n+1}[i] = d_n[i] + \Psi_n(s_5[n])\hat{a}^*[n-i] \qquad i = 1...N$$

where $d_n[i]$ is the i-th tap of the decision feedback filter after calculation of n outputs, $\hat{a}[n]$ is a sequence of detected data, and $\Psi_n(\cdot)$ is a complex valued function, whose parameters may depend on the symbol index n.

4. The communication receiver according to claims 1-3, where some values of n:

$$\varphi_n(x) = \delta[n]\left(\mathrm{Re}^2(x) - k_2\right)\mathrm{Re}(x)$$

where $\mathrm{Re}(\cdot)$ denotes the real part of a complex number, k_2 is a scalar, and $\delta[n]$ n=1,2,... is a sequence of numbers.

5. The communication receiver according to claims 1-3 , where for some values of n

$$\varphi_n(x) = \delta[n]\left(|x|^2 - k\right)x$$

where k is a scalar, and $\delta[n]$ is a sequence of numbers.

6. The communication receiver according to claims 1-3 , where some values of n:

$$\varphi_n(x) = \delta[n](x - \hat{a}(x))$$

where $\hat{a}(x)$ is the result of a memoryless nearest neighbor symbol detector whose input is x, and $\delta[n]$ is a sequence of numbers.

7. The communication receiver according to claims 1-6, where some values of n:

$$\Psi_n(x) = \delta[n]\left(\mathrm{Re}^2(x) - k\right)\mathrm{Re}(x)$$

where k is a scalar, and $\delta[n]$ n=1,2,... is a sequence of numbers.

8. The communication receiver according to claims 1-6 , where for some values of n

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$$\Psi_n(x) = \delta[n](|x|^2 - k)x$$

where k is a scalar, and $\delta[n]$ is a sequence of numbers.

9. The communication receiver according to claims 1-6, where some values of n:

$$\Psi_n(x) = \delta[n](x - \hat{a}(x))$$

where $\hat{a}(x)$ is the result of a memoryless nearest neighbor symbol detector whose input is x, and $\delta[n]$ is a sequence of numbers.

10. A digital communication system that employs the communication receiver according to claims 1-9 and a QAM transmitter.

11. A digital communication system that employs the communication receiver according to claims 1-9 and a CAP transmitter.

12. A digital communication system that employs the communication receiver according to claims 1-9 and a VSB transmitter.

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Figure 1

Digital Communications System

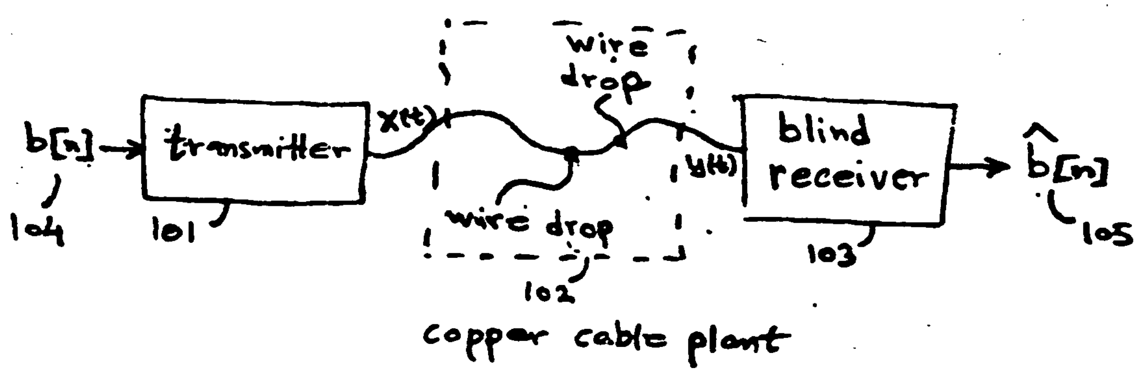

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Figure 2 - Transmiter

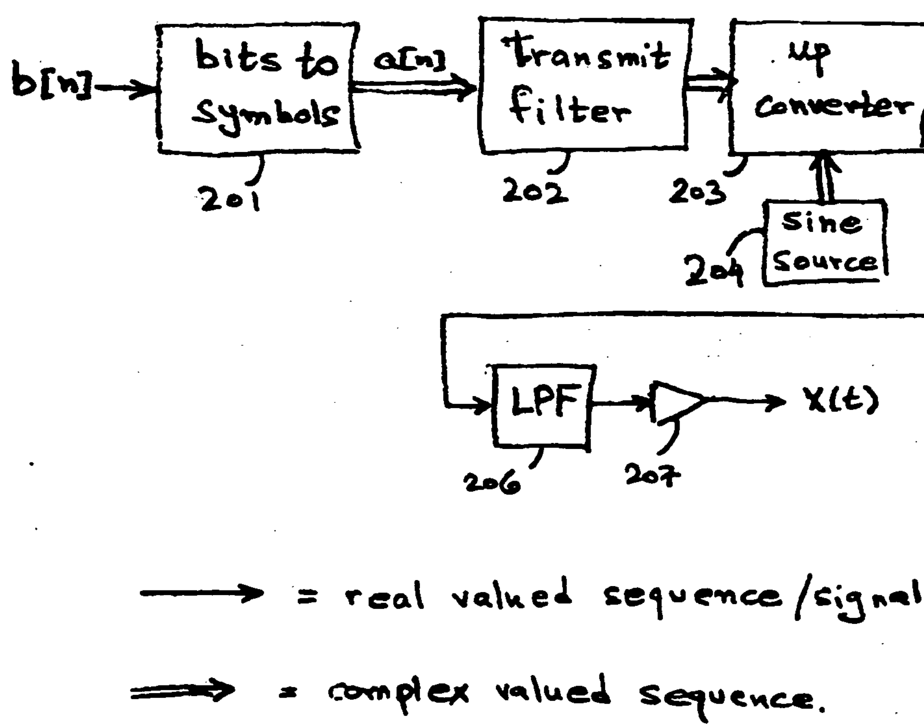

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Figure 3 - Blind Receiver

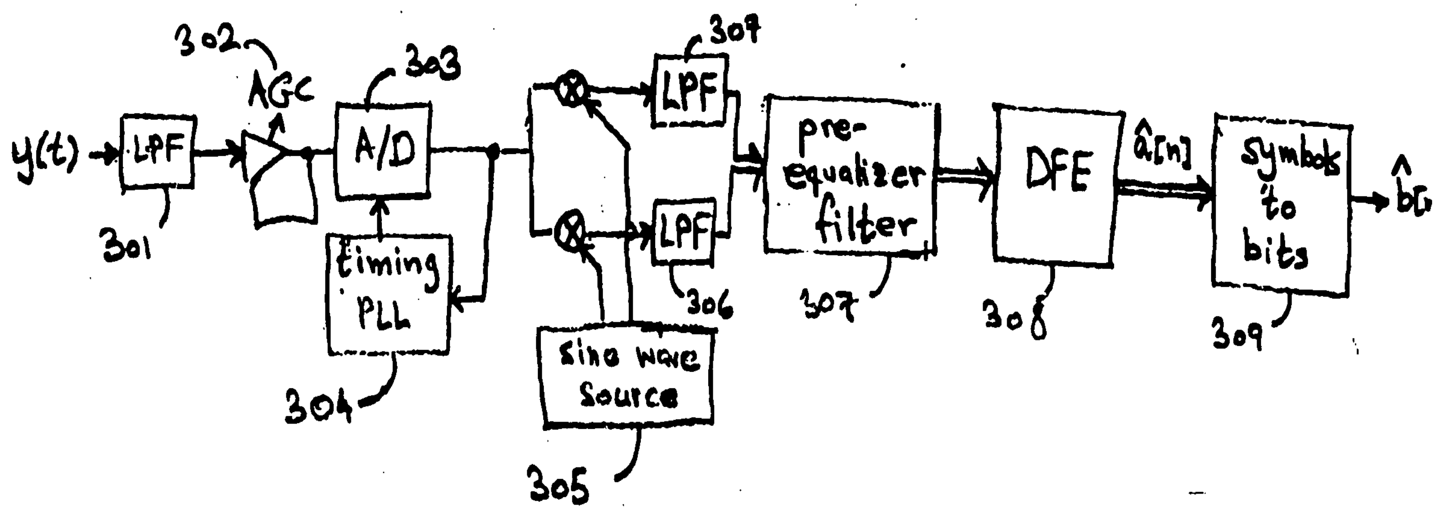
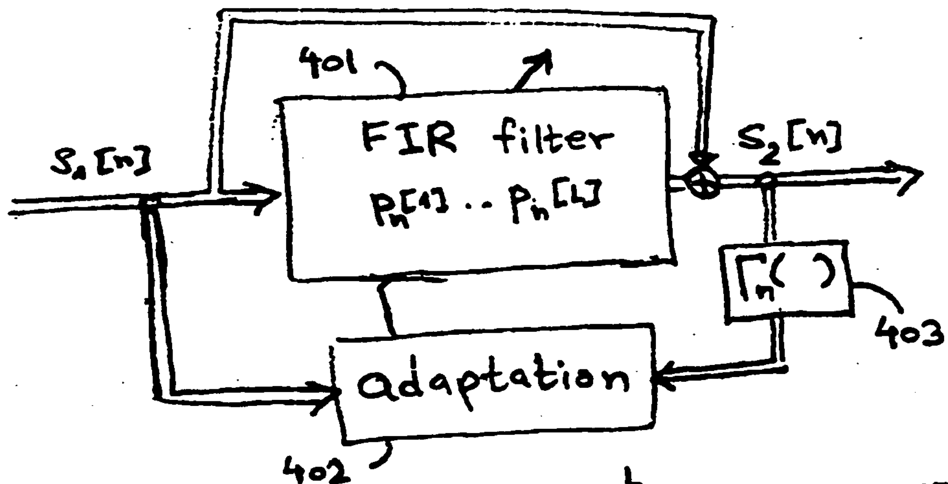


Figure 4

Pre-Equalizer Filter

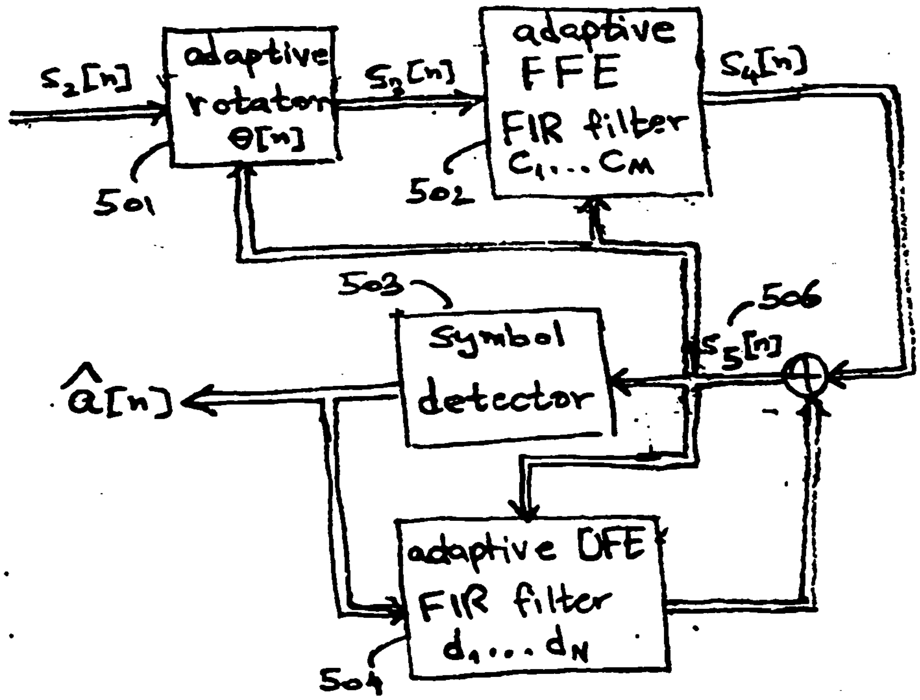


$$S_2[n] = S_1[n] + \sum_{\ell=1}^{L} p_n[\ell]\, S_1[n-\ell] \quad (L \geq 0)$$

$$p_{n+1}[\ell] = p_n[\ell] + \Gamma_n(S_2[n]) \cdot S_1^*[n-\ell] \quad \ell = 1 \ldots L$$

$$\Gamma_n(x) = \delta_p[n] \cdot x$$

Figure 5 - DFE



$$s_3[n] = s_2[n] \cdot e^{j\theta[n]}, \qquad \theta[n+1] = \theta[n] + \rho_n(s_5[n])$$

$$s_4[n] = \sum_{m=1}^{M} c_n[m]\, s_3[n-m], \qquad c_{n+1}[m] = c_n[m] + \varphi_n(s_5[n])\, s_3^*[n-m]$$

$$s_5[n] = s_4[n] + \sum_{i=1}^{N} d_n[i]\, \hat{a}[n-i], \qquad d_{n+1}[i] = d_n[i] + \psi_n(s_5[n])\, \hat{a}^*[n-i]$$

$(M \geq 1,\ N \geq 0)$

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